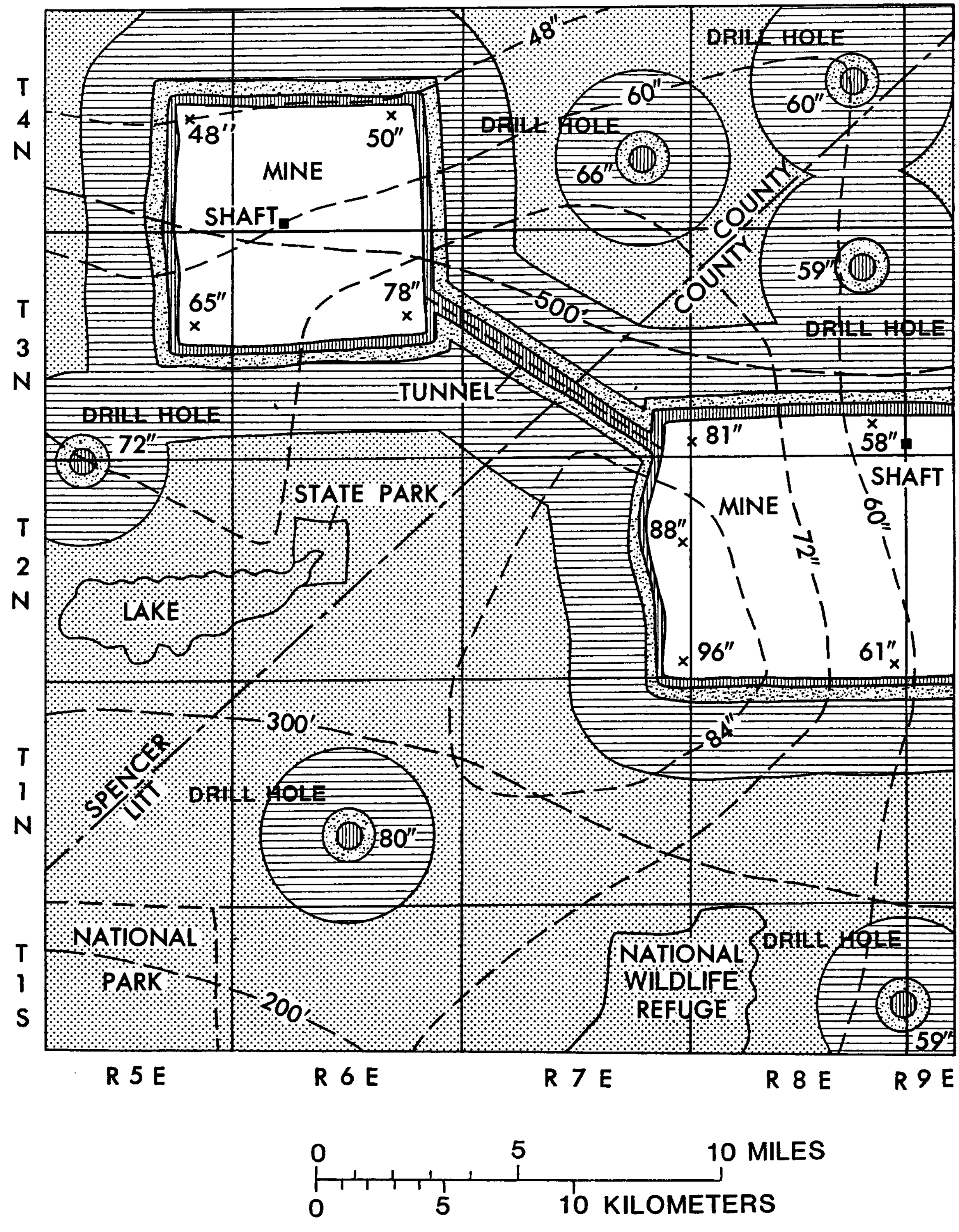

FIGURE 21.—Flat-lying bituminous coal bed with data only from underground mined areas and drill holes. Note pattern areas of reliability around each drill hole and paralleling the boundaries of mined areas and the tunnel that connects the mines. Numerous thickness of coal measurements along tunnel and mine boundaries are not shown. Coal tonnages and acreages should be reported separately for each resource category, as determined by areas of reliability; the 0–200 foot, 200–300 foot, 300–500 foot, and >500-ft

Density logs should be used in conjunction with other logs to avoid mistaking spurious low-density readings for coal. These logs are generally recorded simultaneously with a gamma ray log, which resolves most uncertainties of rock identification.

NEUTRON LOG

The neutron log, which is similar to the density log, records the varying intensity of gamma rays resulting from inducing neutrons into rocks adjacent to a drill hole by a probe containing a radioactive source. In general, the number of gamma rays and neutrons detected as they return to a detector in the probe are inversely proportional to the hydrogen ion content of a particular rock type. The curve recorded by the detector of returning gamma rays and neutrons can be interpreted to indicate the relative fluid content of the rocks and therefore their porosity and permeability. This log is commonly called the porosity index. The curve of the neutron log records high readings adjacent to permeable fluid-filled rocks because of their high hydrogen contents, but it also records high adjacent to a coal bed because of its high carbon content (fig. 31). A clay with high-moisture content will also record high reading on this curve. Therefore, a high-moisture clay adjacent to a coal bed can obscure the contact between the clay and coal and record a spurious thickness of coal. Other types of logs such as the density or gamma ray will allow a more accurate measurement of the thickness of coal. Neutron logs are also strongly affected by caved or oversized diameter holes; therefore, neutron logs should be used in conjunction with caliper logs.

ACOUSTIC VELOCITY LOG

Acoustic velocity logs record the velocity of pulsed sonic waves generated in a probe, transmitted into rocks surrounding the probe in a drill hole, and reflected to receivers in the probe. The results are recorded as the inverse of velocity—that is, the time in microseconds for the waves to travel 1 foot (interval transit time). The velocity of the sonic wave depends both upon the lithology and the porosity of the rock type being penetrated. If the rock type is known, therefore, the acoustic velocity log can be used as a measure of porosity. A decrease in velocity (increase in interval transit time) can be interpreted to be the result of an increase in porosity. Coal generally has a longer interval transit time (lower velocity) than adjacent rocks. Because an acoustic velocity log can record velocity changes in great detail, it is commonly recorded on an expanded scale (1 inch = 20 feet) along with a gamma ray and caliper log. However, its value as a tool for identifying coal beds is dependent on the nature of the coal-bearing sequence. An acoustic velocity log is an excellent tool in deeply buried rocks such as the Tertiary rocks of southwest Wyoming. Acoustic velocity logs can be used to delineate coal beds with precision (see fig. 29). They are of lesser value where the same rocks are near the surface, are poorly consolidated, or are fractured because the many spurious low-velocity deflections are recorded. Such logs are everywhere useful in distinguishing coal from limestone, which has a much shorter interval transit time.

MEASUREMENT OF THE COAL BED THICKNESS

The measurement of thickness of coal beds on geophysical logs requires the identification of the top and base of the coal beds by either of the following methods: (1) point of inflection method (the points where curves change direction), or (2) midpoints of inflection method (arbitrary points located midway between the points of inflection). The points of inflection method is used for measuring the thickness of coal on gamma ray logs, on resistivity logs, and for thin beds on density, neutron, and acoustic velocity logs. It is important to understand that the thickness of coal measured on the short normal and long normal resistivity curves is less than the true thickness of the coal bed by the amount of the electrode spacing; that is, 16 inches less for the short normal curve, and 64 inches less for the long normal curve. The midpoints of inflection method is used to identify the top and base of thick coal beds on the density, neutron, and acoustic velocity logs (see figs. 26, 27 29, and 30 for examples). In general, the SP, long normal resistivity, lateral resistivity, and induction curves are not suitable for accurate measurement of the thickness of coal beds.

The precision and accuracy of coal bed thickness measurements on geophysical logs are dependent on several factors, such as the speed of logging, the scale at

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overburden categories; counties; areas underlying the lake; State and national parks and the National Wildlife Refuge; and each township and range. The 200-, 300-, and 500-foot overburden contour lines and the coal isopachs were constructed to define depth of burial and average thickness of coal in each areal category. Explanation for patterns of resource categories is in figure 19.

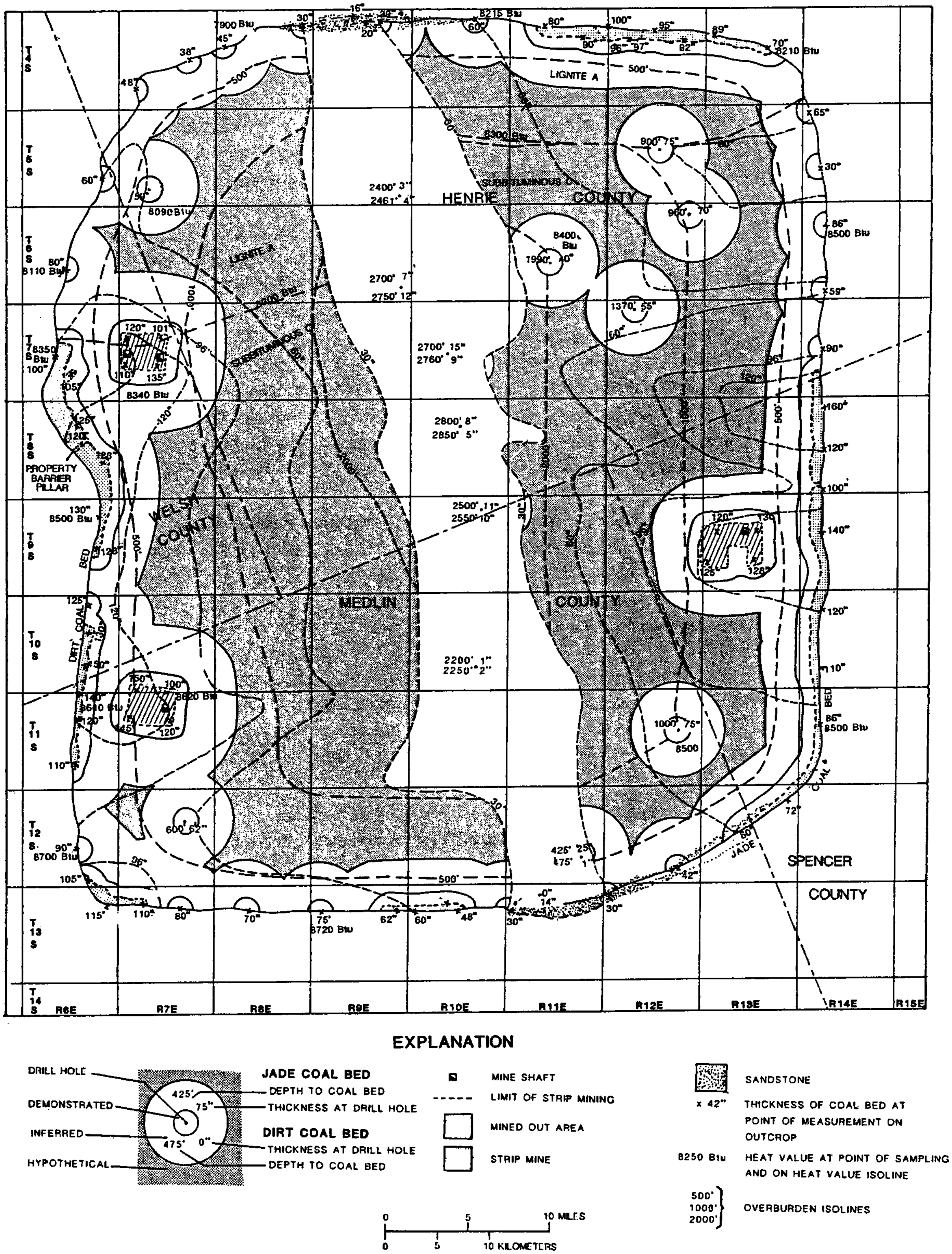

FIGURE 22.—A small coal basin containing two coal beds that thin out into sandstone by intertonguing. Area of intertonguing sandstone and coal beds trends slightly west of north and is marked by absence of coal beds or by coal too thin to mine. Note 8,300 Btu isolines trending about east-west. Isolines mark approximate areal boundaries between lignite A and subbituminous C coal as defined by heat value on a moist, mineral-matter-free basis. Coal tonnages should be computed as follows: by demonstrated, inferred, and hypothetical categories; by mined out (underground and strip); by 0–500 feet

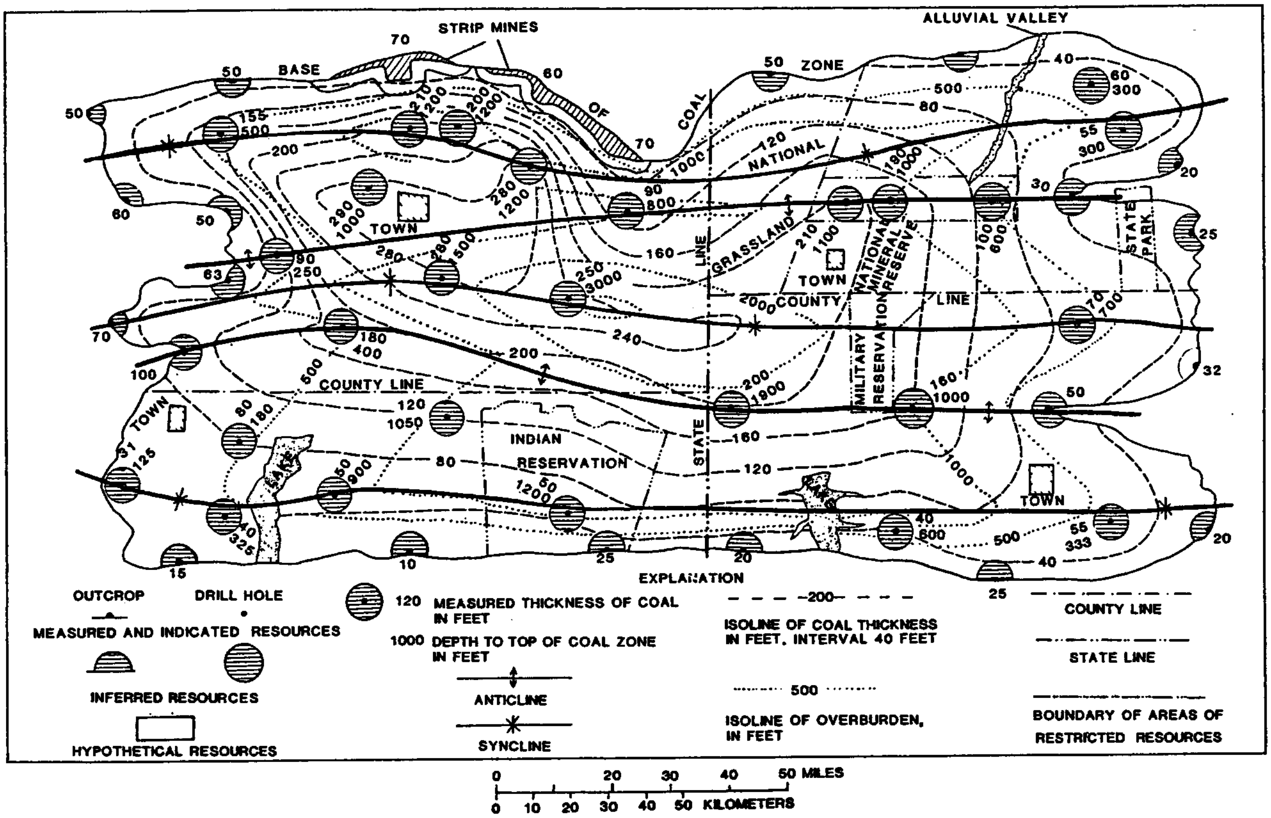

FIGURE 23.—A large, simple coal basin containing a large quantity of subbituminous coal and lignite. Coal occurs in a zone as thick as 500 feet. Information on coal zone is derived from two strip mines, 20 exposed localities where coal-bearing rocks can be measured, described, and correlated, and numerous oil and gas wells for which there are drill cuttings, cores, and (or) geophysical logs. Demonstrated, inferred, and hypothetical areas of reliability are based on points of control from the surface exposures and wells. Townships and ranges and rank differences are not shown on map because of density of detail. Coal should be categorized and tonnages estimated by States; counties; townships and ranges; rank; demonstrated, inferred, and hypothetical areas of reliability; 0–500 feet (0–150 m), 500–1,000 feet (150–300 m), 1,000–2,000 feet (300–600 m), 2,000–3,000 feet (600–900 m), and 3,000–6,000 feet (900–1,800 m) categories of overburden; thickness of coal in coal zone; and coal underlying Indian reservations, military reservations, national grasslands, national mineral reservations, and State park categories. Coal beneath Indian reservations, towns, lakes, and alluvial valleys could be tabulated separately from other coal resources and those that are restricted so labeled. Cumulative total thickness of coal at a point of surface measurement or well is the summing of all coal in beds greater than 2.5 feet thick.

which the log is recorded, the type of log, the type of equipment, and the instrument settings as well as the ability of the user to pick the correct top and base of a coal bed.

Density, neutron, gamma ray, and acoustic velocity logs in oil and gas wells are recorded at speeds of 30 to 60 feet per minute and at a scale of 1 inch equals 20 feet. Such logs generally permit the measurement of the thickness of coal beds within an error of ±1 foot and allow identification of coal beds as thin as about 2 feet. A suite of logs run in a coal exploratory drill hole at slow speeds of 15 feet or less per minute and recorded at 1 inch equals 10 feet or less, with a standard mineral probe and recording instruments set for coal identification, can measure coal beds as thin as ±0.5 foot. The use of special equipment and slower logging speeds can improve the precision of thickness measurements.

Resistivity logs of oil and gas wells generally are run at higher speeds of about 100 feet per minute and are recorded at 1 inch equals 50 feet, with the result that coal beds thinner than about 2 feet cannot be identified or measured as to thickness. Some of the focusing electrode logs recorded at 1 inch equals 20 feet may permit greater precision. In contrast with oil and gas logs, logs

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(0–150 m), 500–1,000 feet (150–300 m), 1,000–2,000 feet (300–600 m), and 2,000–3,000 feet (600–900 m) overburden categories; by 30–60 inches (75–160 cm), 60–96 inches (150–240 cm), 96–120 inches (240–300 cm), and 120–240 inches (300–600 cm) thickness of coal categories; by rank of coal (lignite A and subbituminous C), and by townships and ranges, counties, coal field, basin, and State.

Coal reserves or resources of ____________ Township, Range _________, Quadrangle ________, Field ________, County, State of ____________

Formation_______, Member ________, Rank of Coal_________, Sulfur Content_______, Ash Content_______, Heat Value (Btu Cal)____

Name of Bed	Overburden Range (feet)	Planimeter Reading	Area (Acres)	Weighted Average Thickness (inches)	Remaining or Original Tonnage (millions of short tons)[1]											
					Measured (inches)				Indicated (inches)				Inferred (inches)			
					14-28	28-42	42-84	84-168	14-28	28-42	42-84	84-168	14-28	28-42	42-84	84-168
			Column total													

Planimeter factor ____________

Short or metric tons per acre-inch ____________ Total Measured ________ Total Indicated ________ Total Inferred ________

Planimetered by ________ Total 14-28"________ Total 28-42"________ Total 42-84"________ Total 84"+________

Calculated by ____________ Total 0-500'________ Total 500-1,000'________ Total 1,000-2,000'________

Checked by ____________ Total 2,000-3,000'________ Total 3,000-6,000________

Grand Total ________

[1]Categories for hypothetical and speculative coal may be added.

FIGURE 24.—Suggested type of form for recording data and computed tonnages for a mine, area, coal bed, quadrangle, township and range, coal field, basin, region, province, county, State or political province, and the Nation.

FIGURE 25.—Suggested format for tabulating data and calculating tonnages with headings left to judgment of estimator.

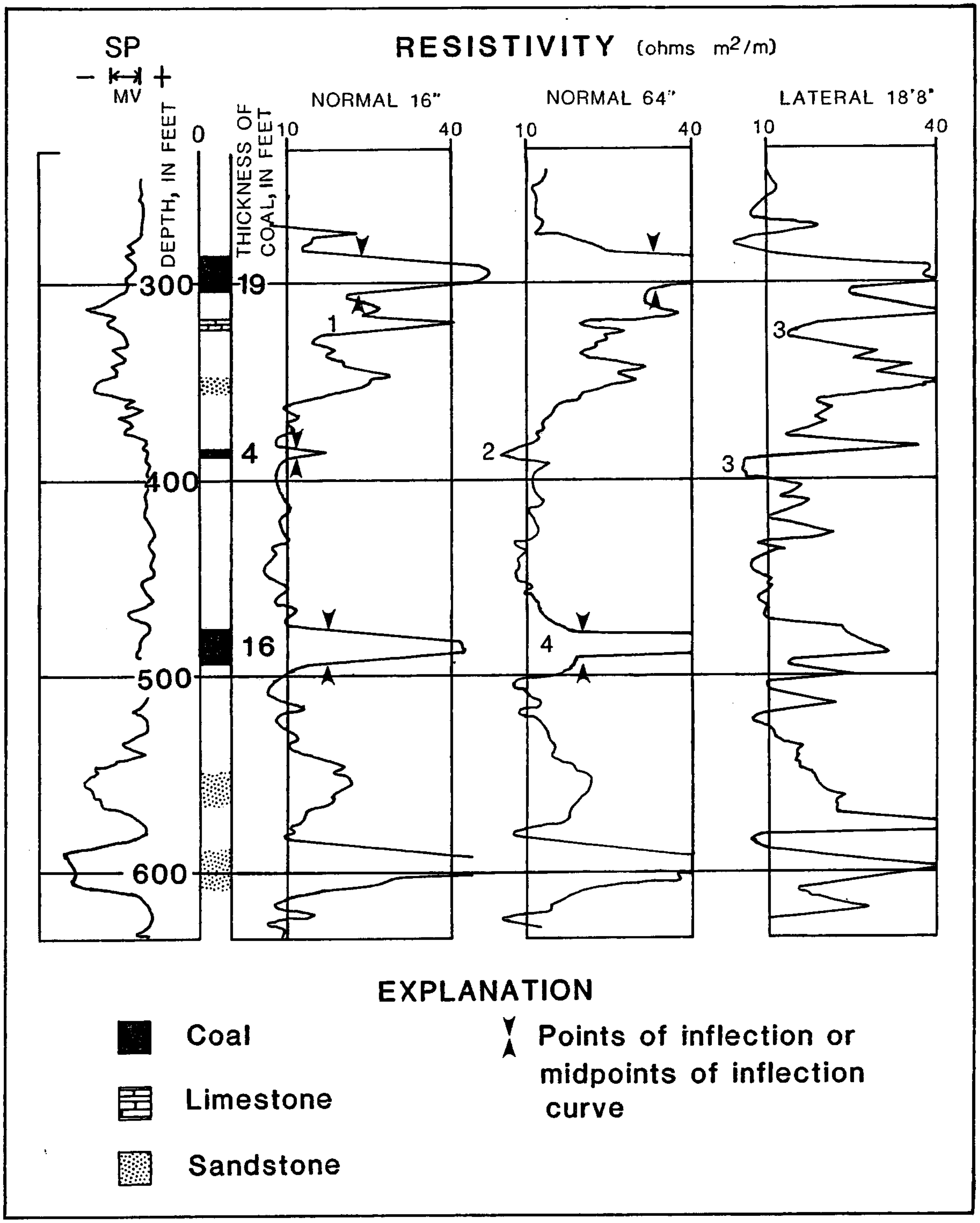

FIGURE 26.—Early conventional electric log (1957) of the Owanah Kendrick No. 1 well in Big Horn County, Montana, showing response of subbituminous coal beds in the Paleocene Fort Union Formation. Short normal peak at 320 feet (1) looks like a coal bed, but is identified as limestone on the acoustic velocity log of a nearby hole. Noteworthy are long normal reversals (2) where the resistive bed is thinner than the electrode spacing of 64 inches, and the high lateral resistivity response opposite a thin resistive bed (3), with low response just below bed, and at where the long normal curve indicates that the bed is 4 feet thinner than does the short normal curve (4) because of the difference in electrode spacing. Note also the large SP response of the sandstone beds compared to coal.

Stagg Dec. -- Exhibit 2
APP. III 695

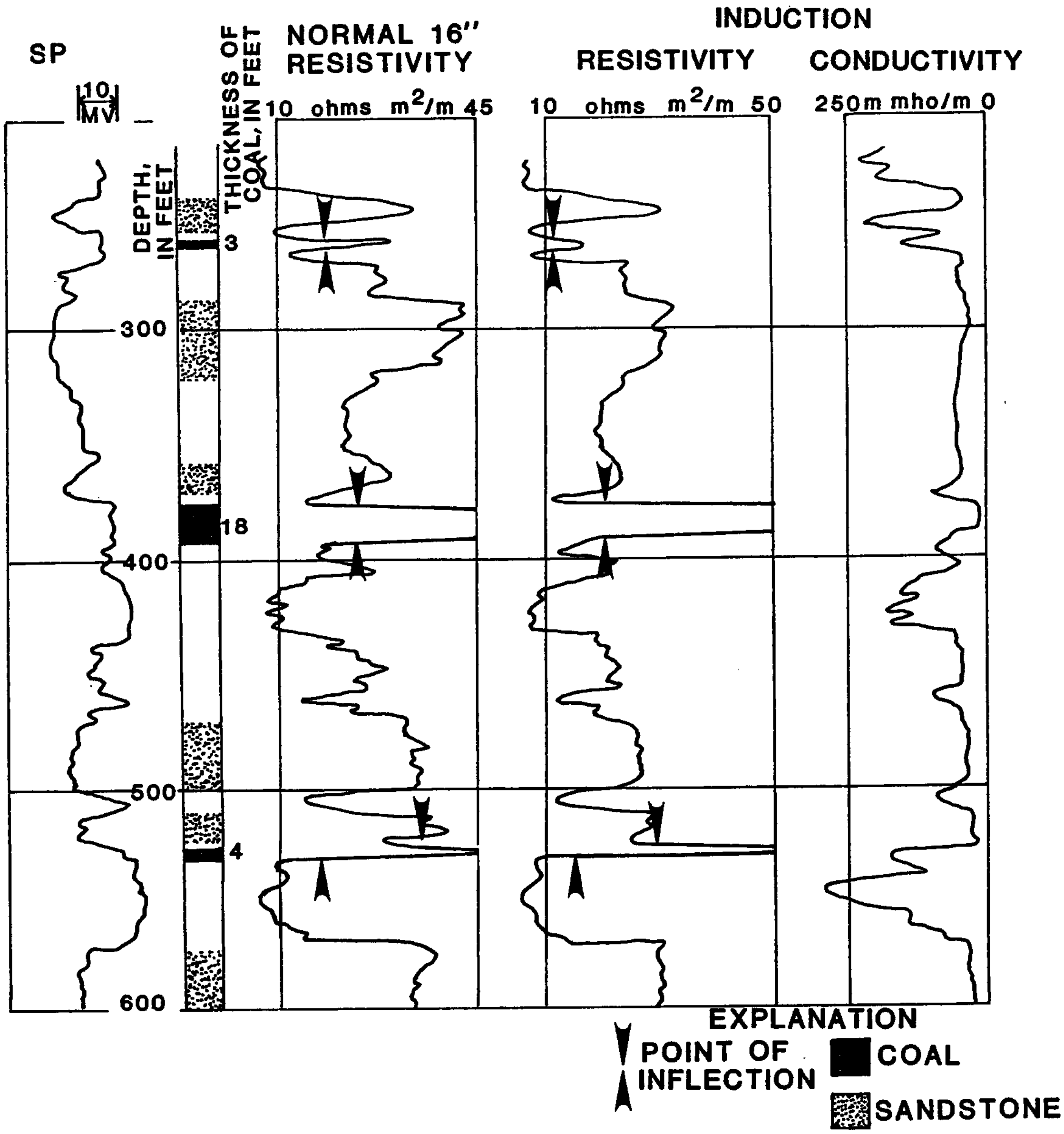

FIGURE 27.—Induction and conductivity geophysical logs (1960) of the Hose-Austin Drilling Company, Bones Brothers No. 1 well, Rosebud County, Montana, showing response of subbituminous coal in Paleocene Fort Union Formation.

of the "single point" resistivity type in coal exploration drill holes can provide precision similar to those of radiation-type logs.

COMPOSITION AND RANK OF COAL

Geophysical logs can also provide information on the composition and rank of coal. High-ash or shaly zones (partings) in coal generally are recorded on logs by curves indicating that they are more radioactive, more dense, and less resistive than purer coal. High-rank coal is more dense and has a shorter interval travel time in sonic logs than low-rank coal. Efforts have been made to quantify compositional factors of coal, such as moisture and ash content, using geophysical logs. Bond and others (1971) report that in the Illinois basin an experimental program using computer processed data from logs of coal exploratory drill holes produced excellent determinations of moisture and ash in coal. However,

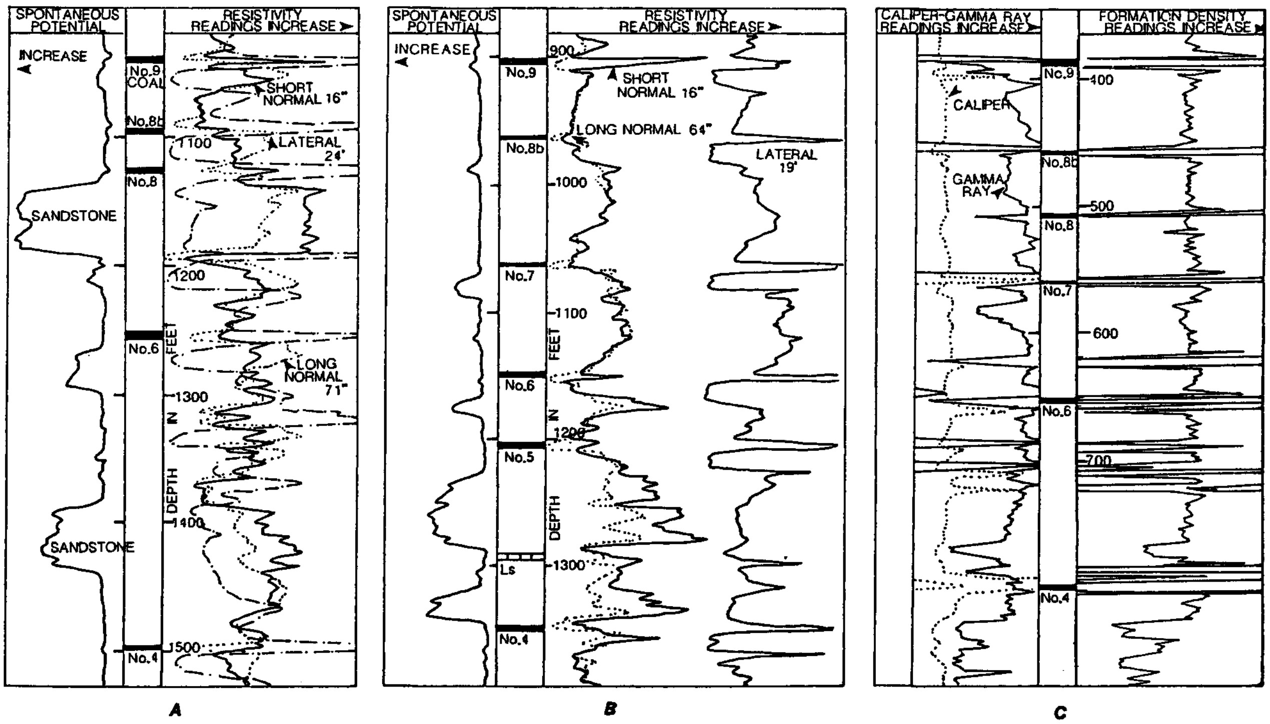

FIGURE 28.—Examples of oil- and gas-well geophysical logs from western Kentucky that can be used for coal bed correlations and coal resource evaluations.

attempts to quantify coal composition using geophysical logs from wells in the Northern Great Plains have had erratic results.

STRATIGRAPHY AND STRUCTURE

Geophysical logs that have been properly related to a known stratigraphic section can be used to correlate coal beds and determine their structure. In many areas a coal bed and adjacent rocks are recorded on geophysical logs as a unique curve, or sets of curves, that can be recognized on logs of drill holes throughout a large area (see fig. 28, No. 9 coal bed). Recognition of "signature" curves permits correlation of stratigraphic units across any area where the lithology remains reasonably constant and in some places allows correlation throughout a coal basin. Properly correlated logs can provide the necessary data to construct coal bed maps that show structure, thickness of coal, and thickness of overburden.

Geophysical logs are also useful in studying the ancestoral sedimentary environments of coal beds. In the Appalachian coal region, Wanless and others (1963) used electric logs of oil and gas wells augmented by drill-hole and outcrop data to identify and map sedimentary environments of some coal-bearing rocks of Pennsylvanian age. Daniels and Scott (1980; 1982) in Kentucky and in Montana used geophysical logs of coal drill holes to refine their interpretations of drillers' lithologic logs in a study of ancestoral sedimentary swamp environments of Pennsylvanian and Tertiary rocks.

SUMMARY

Geophysical logs of oil and gas wells are the source of abundant data on coal beds, but the value of any of these logs in any particular coal area or basin depends in large part on a knowledge of the coal-bearing rocks and of how the data are recorded on the curves of the geophysical logs. Consequently, it is advisable for those planning to use geophysical logs for coal interpretation to study the logs of drill holes in an area where the lithology is known to determine the reaction of logging equipment to various rock types. Use of a suite of several types of logs is recommended for the best results.

It is important to recognize and discard poor quality or ambiguous logs so that erroneous data is not used in calculating coal resources.

Stagg Dec. -- Exhibit 2
APP. III 697

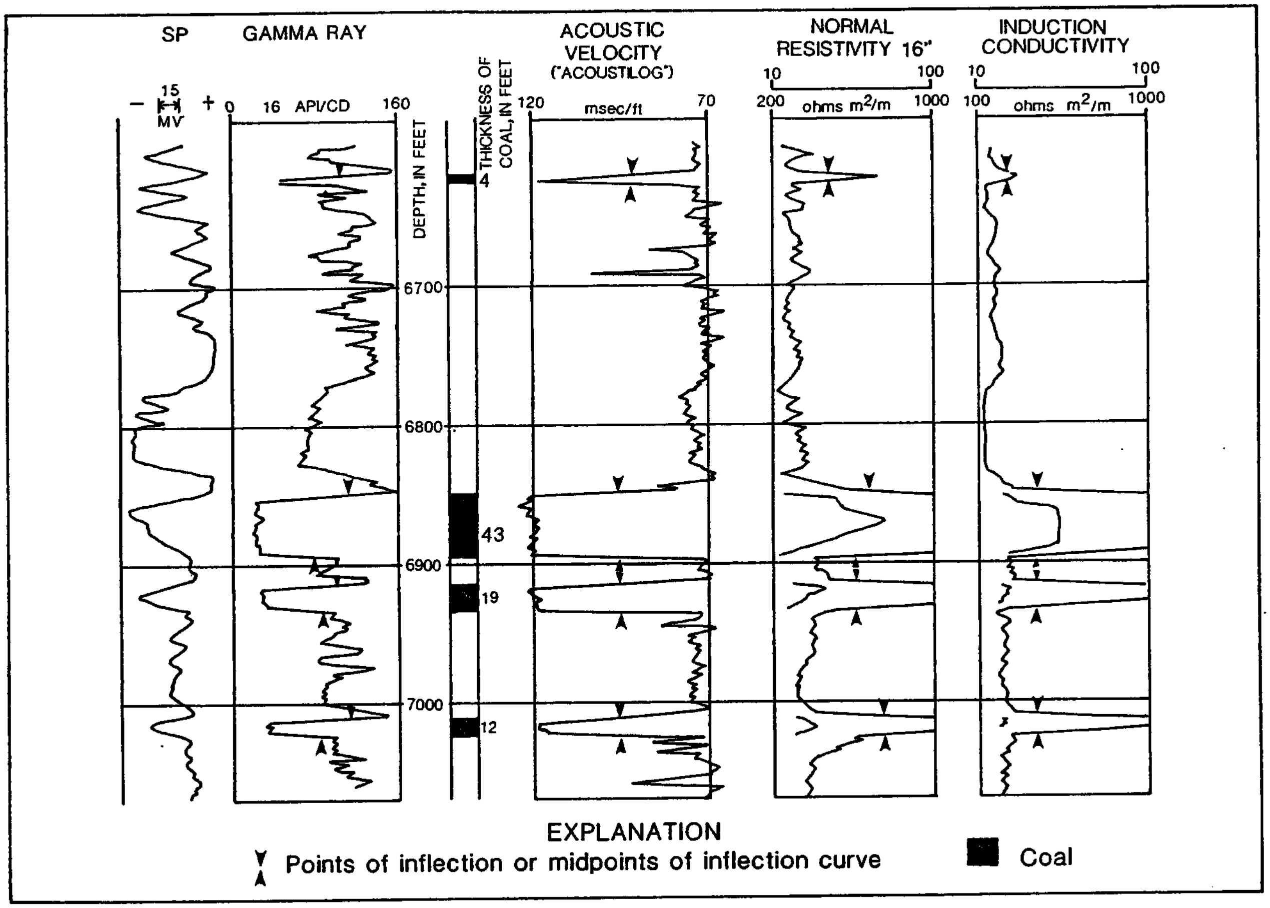

FIGURE 29.—SP, gamma ray, acoustic velocity (sonic), normal resistivity, and induction conductivity logs (1971) from the Davis Oil Grady Fed No. 1-2 well, Sweetwater County, Wyoming, showing response of subbituminous(?) coal beds in the Paleocene Fort Union Formation.

INTENDED AUDIENCE

This circular was prepared for two audiences: (1) coal resource specialists, coal geologists, and coal-mining engineers; and (2) the public, Congress, and many State and Federal agencies who desire more than a casual knowledge about the need for and procedures of coal resource classification.

The definitions, criteria, guidelines, and illustrations are designed to aid coal geologists and engineers in preparing their reports by providing guidance in calculating, categorizing, and describing the coal resources/reserve base/reserves they are evaluating. The description of geophysical log usage also should provide aid in obtaining and using subsurface information on the areal extent, thickness, and correlation of coal beds and should open up a vast and generally untapped data source for most coal geologists. Adherence to the categories of resource assignment, to the definitions, and to the criteria can result in more accurate, precise, explicit, and consistent reports.

The classification system and terminology described in this circular are equally applicable to hand and computer system determinations of resources and reserves. The illustrations are applicable to manual methods of coal resource/reserve base/reserve tonnage estimations. Computer programs have been designed that will yield similar tonnage estimates of coal resources. Those wishing to inquire about the computer software and methodologies should write to Chief, Branch of Coal Resources, 956 National Center, U.S. Geological Survey, Reston, Virginia 22092.

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APP. III 698

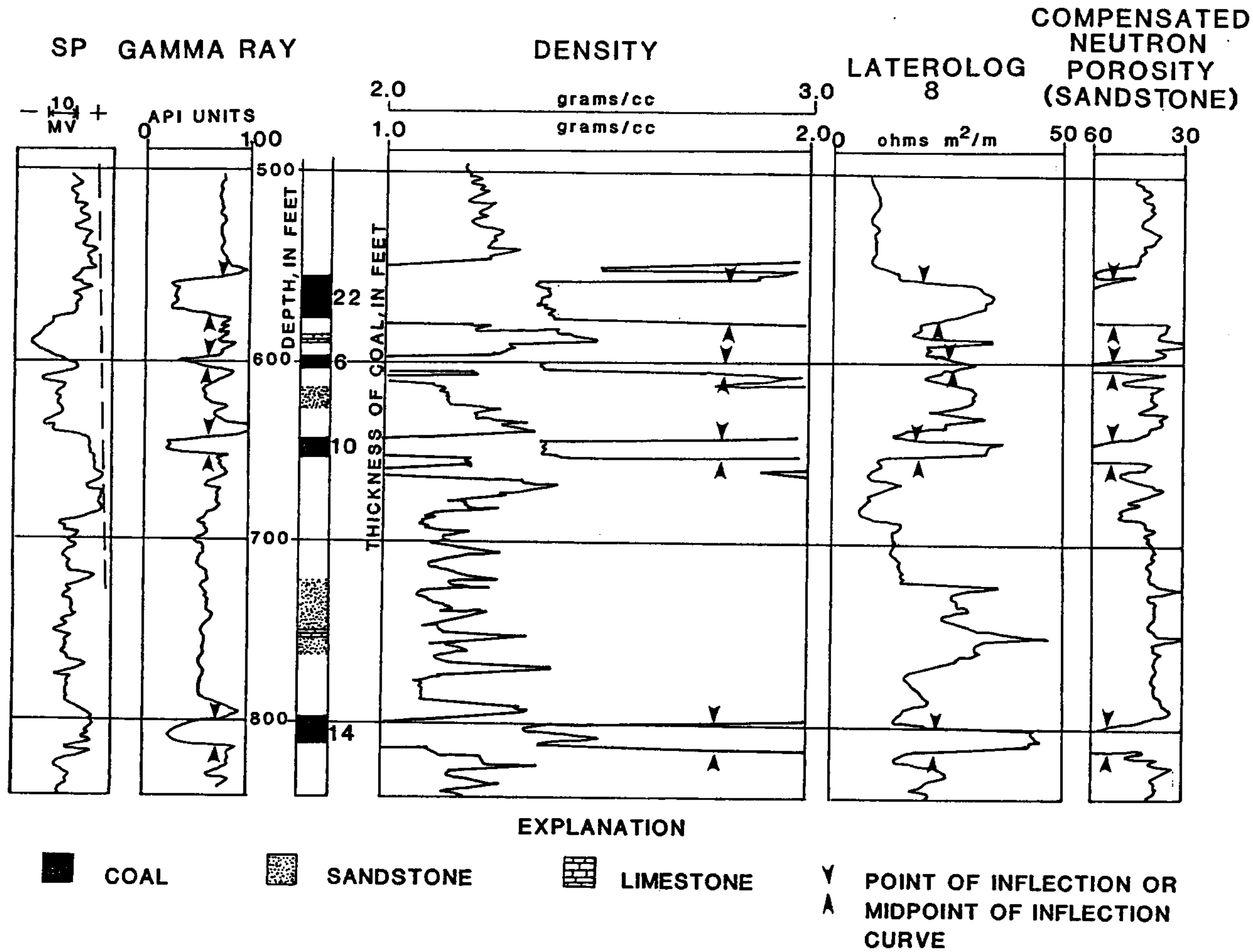

FIGURE 30.—SP, gamma ray, density, dual induction-lateral log, and neutron logs (1978) from Getty Tri-County No. 1 well, Rosebud County, Montana, showing response of subbituminous coal in the Paleocene Fort Union Formation.

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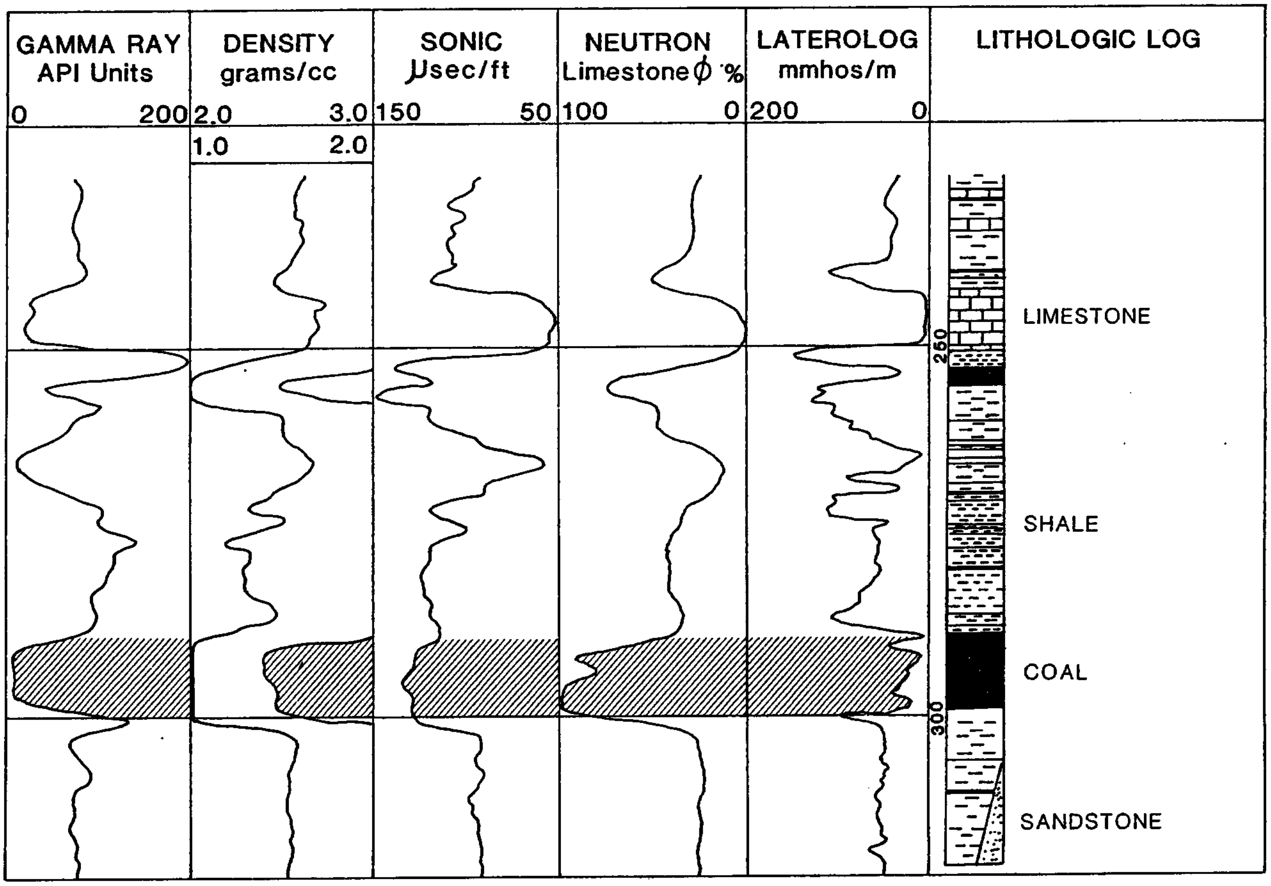

FIGURE 31.—Five geophysical logs of a coal exploration drill hole in the Illinois basin (Midcontinent region) showing response of bituminous coal and limestone of Pennsylvanian age on gamma ray, density, neutron, acoustic velocity (sonic), and lateral logs. Modified from Bond, Alger, and Schmidt (1971).

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